36481 Intake
R7. IA. Duane Arnold

Duane Arnold Energy Center

# CEDAR RIVER OPERATIONAL ECOLOGICAL STUDY

ANNUAL REPORT

January 1990 - December 1990

Prepared by


Donald B. McDonald
Iowa City, Iowa


March 1991

TABLE OF CONTENTS

## INTRODUCTION

This report presents the results of the physical, chemical, and biological studies of the Cedar River in the vicinity of the Duane Arnold Energy Center during the 17th year of station operation (January 1990 to December 1990).

The Duane Arnold Energy Center Operational Study was implemented in mid-January, 1974. Prior to plant start-up extensive preoperational data were collected from April, 1971 to January, 1974. These preoperational studies provided a substantial amount of "baseline" data with which to compare the information collected since the station became operational. The availability of 17 years of operational data, collected under a variety of climatic and hydrological conditions, provides an excellent basis for the assessment of the effects of the operation of the Duane Arnold Energy Center on the limnology and water quality of the Cedar River. Equally important is the availability of sufficient data to identify long-term trends in the water quality of the Cedar River which are unrelated to station operation, but are indicative of climatic patterns, changes in land use practices, or pollution control procedures within the Cedar River basin.

## SITE DESCRIPTION

The Duane Arnold Energy Center, a nuclear fueled electrical generating plant, operated by the Iowa Electric Light and Power Company, is located on the west side of the Cedar River, approximately two and one-half miles north-northeast of Palo, Iowa, in Linn County. The plant employes a boiling water nuclear power reactor which produces approximately 560 MWe of power (1650 MWth) at full capacity. Waste heat rejected from the turbine cycle to the condenser circulating water is removed by two closed loop induced draft cooling towers which require a maximum of 11,000 gpm (ca. 24.5 cfs) of water from the Cedar River. A maximum of 7,000 gpm (ca. 15.5 cfs) may be lost through evaporation, while 4,000 gpm (ca. 9 cfs) may be returned to the river as blowdown water from the cool side of the cooling towers.

## OBJECTIVES

Studies to determine the baseline physical, chemical, and biological characteristics of the Cedar River near the Duane Arnold Energy Center prior to plant start-up were instituted in April of 1971. These preoperational studies are described in earlier reports.[1-3] Data from these studies served as a basis for the development of the operational study.

The operational studies were designed to identify and evaluate any significant effects of chemical or thermal discharges from the generating station into the Cedar River, as well as to assess the magnitude of impingement of the fishery on intake screens or entrainment in the condenser make-up water. These were first implemented in January, 1974 and have continued without interruption through the current year.[4-19]

The specific objectives of the operational study are twofold:

1. To continue routine water quality determinations in the Cedar River in order to identify any conditions which could result in environmental or water quality problems.
2. To conduct physical, chemical, and biological studies in and adjacent to the discharge canal and to compare the results with similar studies executed above the intake. This will make possible the determination of any water quality changes occurring as a result of chemical additions or condenser passage, and to identify any impacts of the plant effluent on aquatic communities adjacent to the discharge.

## STUDY PLAN

During the operational phase of the study sampling sites were established in the discharge canal and at four locations in the Cedar River (Figure 1): 1) upstream of the plant at the Lewis Access Bridge (Station 1); 2) directly upstream of the plant intake (Station 2); 3) at a point within the mixing zone approximately 140 feet downstream of the plant discharge (Station 3); and 4) adjacent to Comp Farm, located about one-half mile below the plant (Station 4). Samples were also taken from the discharge canal (Station 5).

Prior to 1979, samples were collected and analyzed by the Department of Environmental Engineering of the University of Iowa. From January, 1979 through December, 1983 samples were collected and analyzed by Ecological Analysts, Inc. Since 1984 collection and analysis of samples has been conducted by the University of Iowa Hygienic Laboratory, located in Iowa City, Iowa. The conclusions contained in this annual report are based on the results of their analyses. Samples for routine chemical, physical, and biological analysis were taken twice per month, while other studies were conducted seasonally. The following are discussed in this report:

I. <u>General Water Quality Analysis</u>

A. Frequency: twice per month

B. Location: at all five stations

C. Parameters Measured:

1. Temperature
2. Turbidity
3. Solids (total, dissolved, and suspended)
4. Dissolved oxygen
5. Carbon dioxide
6. Alkalinity (total and carbonate)
7. pH
8. Hardness series (total and calcium)
9. Phosphate series (total and ortho)
10. Ammonia
11. Nitrate
12. Iron
13. Biochemical oxygen demand
14. Coliform series (fecal and E. coli)

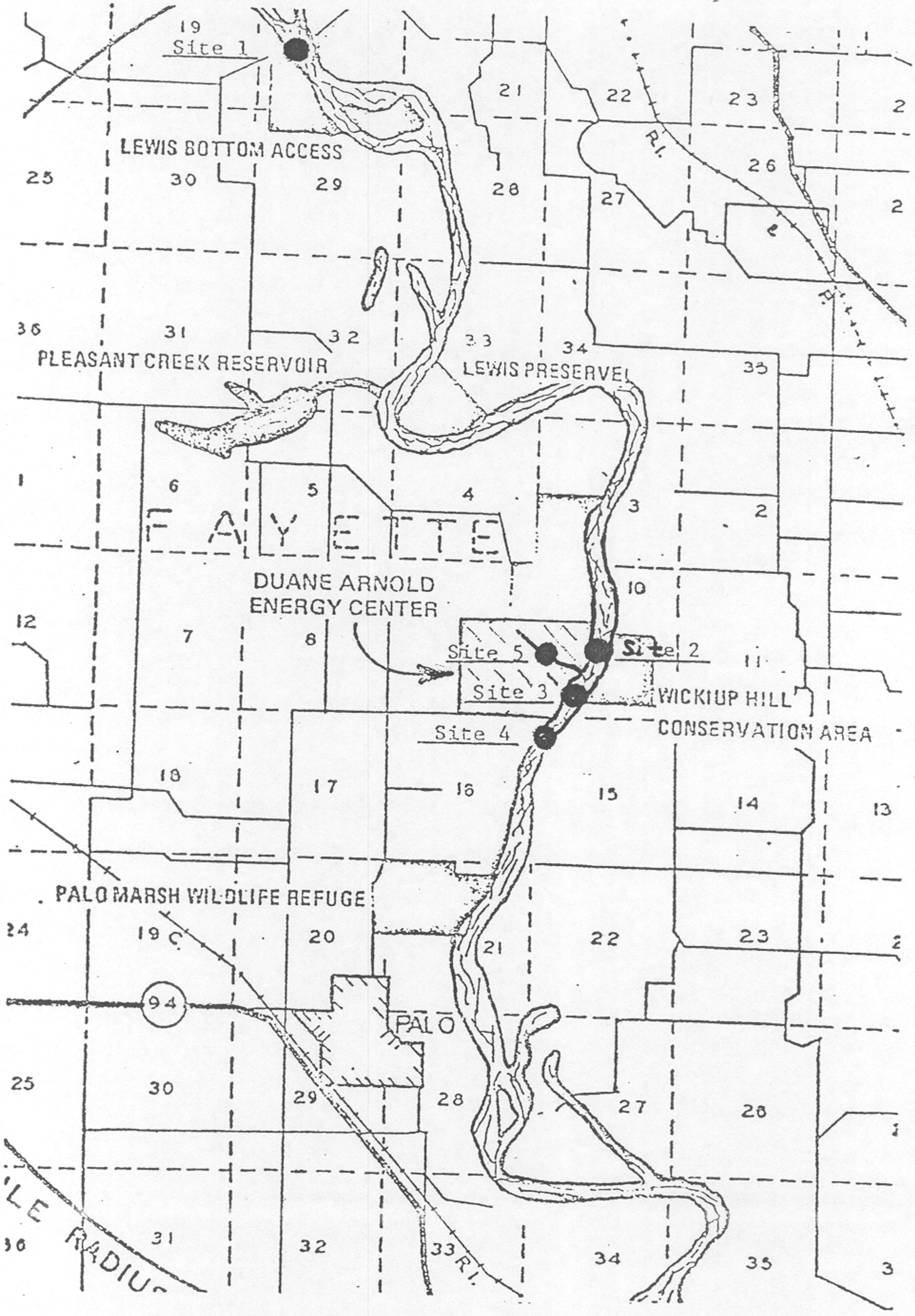


Figure 1. Location of Operational Sampling Sites

II. Additional Chemical Determinations

A. Frequency: twice yearly

B. Location: at all five stations

C. Parameters Measured:

1. Chromium
2. Copper
3. Lead
4. Manganese
5. Mercury
6. Zinc
7. Chloride
8. Sulfate

III. Biological Studies

A. Benthic Studies:

1. Frequency: summer and fall
2. Location: at all five stations

B. Asiatic Clam (*Corbicula*) and Zebra Mussel (*Dreissena*) Surveys:

1. Frequency: twice yearly
2. Location: upstream and downstream of the plant, intake bay, cooling tower basin, and discharge canal. The Zebra mussel survey also includes Pleasant Creek Reservoir.

C. Impingement Studies:

1. Frequency: daily
2. Location: intake structure

## OBSERVATIONS

### Physical Conditions

Hydrology (Table 1)

The low river flows which characterized most of 1988 and 1989 did not persist beyond the spring of 1990. Mean monthly flows ranged from 30% of the median monthly discharge in April to 870% in August. A record high mean monthly as well as a record daily discharge was present in August. Estimated mean flow for the year was ca. 5,061 cfs, somewhat higher than the 19 year average flow of ca. 4,619 cfs. Mean monthly discharges at the Cedar Rapids gauging station ranged from 360 cfs in January to 17,540 cfs in August. Mean monthly discharges in 1990 were classified as deficient (less than the 25% quartile) in January and February, and excessive (greater than the 75% quartile) in June, July, August, and September. Winter flows remained low through early March, ranging from a yearly minimum of 252 cfs on January 3 to 634 cfs on January 18, and then increased to an early spring high of 6,640 cfs by March 18, 1990. Flows declined to less than 2,000 cfs by late March and remained below normal through most of April. May and June flows were substantially higher with peaks of 11,300 and 26,200 cfs, respectively. Flows declined in early July and remained below 7,000 cfs until late in the month when they increased sharply, reaching a record August high of 44,700 cfs on August 2. August flows were far above normal, establishing a record mean discharge for the month. Fall and winter flows were also above normal, ranging from ca. 1,000 to 4,000 cfs. Hydrological data are summarized in Table 1.

Temperature (Table 2)

Ambient river temperatures during 1990 ranged from 0.0$^{o}$C (32.0$^{o}$F) to 25.5$^{o}$C (77.9$^{o}$F). The maximum ambient (Station 1) temperature was observed on June 27. This value was lower than that of either the previous year or the ten year average maximum of 27.2$^{o}$C (81$^{o}$F). Maximum downstream temperatures of 25.0$^{o}$C (77$^{o}$F) were observed both in the mixing zone and one-half mile below the plant (Stations 3 and 4) on June 27 and September 5. The highest discharge canal (Station 5) temperature observed during the period was 32.0$^{o}$C (89.6$^{o}$F), which was also recorded on June 27. A maximum temperature differential ($\Delta$T value) between the upstream river and the discharge canal (Station 2 vs. Station 5) of 18.0$^{o}$C (32.4$^{o}$F) was observed on March 21.

Station operation had little effect on downstream water temperatures. The maximum $\Delta$T value between ambient upstream temperatures at Station 2 and downstream temperatures at Station 3, located in the mixing zone for the discharge canal, of 3.0°C (5.4°F) was measured on March 7. A maximum temperature elevation at the Comp Farm station, one-half mile below the plant (Station 2 vs. Station 4) of 2.0°C (3.6°F) also observed on February 21. There was no instance in which a temperature elevation in excess of the Iowa water quality standard[20] of 3°C was observed. No other samples taken at Station 4 exhibited temperature differentials in excess of 1.5°C (2.7°F) above ambient. A summary of water temperature differentials between upstream and downstream locations is given in Table 3.

Turbidity (Table 4)

Average river turbidity values were somewhat higher than those of the previous two years, due likely to the substantially higher river flows in 1990. Maximum ambient river levels were also higher. Peak values of 140-160 NTU occurred at upstream river locations in late May. Low values (2-10 NTU) occurred during the late fall and winter periods. Turbidity values in the discharge canal continued to be higher than those observed in the upstream river. A maximum discharge canal turbidity of 1,000 NTU was observed on May 23.

Solids (Tables 5-7)

Solids determinations included total, dissolved, and suspended. Total solids values in upstream river samples were generally higher than those observed in 1988 and 1989. Values ranged from 300 to 570 mg/L, with the majority falling between 350 and 450 mg/L.

Dissolved solids values were also higher than those of the previous two years. Upstream values ranged from 220 to 380 mg/L. Lowest values accompanied both low flows in April and a period of very high flow in late August. High values continued to occur in the winter. Dissolved solids values at Station 3, 140 feet downstream of the discharge canal, were generally higher than values observed upstream, but differences were less obvious than those present in 1989. A maximum downstream value of 560 mg/L was observed at Station 3 on March 7.

Suspended solids values at river locations ranged from <1 to 190 mg/L. Low values occurred from January into early March and from mid-November through December, while highest values accompanied higher flows from late May through July.

As in previous years, total and dissolved solids values in the discharge canal were consistently higher than in the river samples. Maximum total solids concentrations of 2,500 mg/L were observed in the discharge canal in late May, while a minimum of 350 mg/L was observed on August 23, when the station was not in operation.

## Chemical Conditions

Dissolved Oxygen (Table 8)

Dissolved oxygen concentrations in river samples collected during 1990 continued to be relatively high, ranging from 6.9 to 20.0 mg/L (84 to 151% saturation). Highest dissolved oxygen concentrations (14-20 mg/L) were observed in the river at intervals from late January to early April, and in November and December in conjunction with clear water and relatively low flow. Lowest values occurred in June and August in conjunction with high river flow.

Dissolved oxygen concentrations in the discharge canal (Station 5) ranged from 6.0 to 12.6 mg/L (74 to 100% saturation). Lowest values occurred in May and June. Highest values were observed in February.

Carbon Dioxide (Table 9)

Carbon dioxide concentrations continued to be low throughout the year, ranging from <1 to 5 mg/L. Most values were below 1 mg/L and were consistently below this level at all river locations from October through December. Maximum levels occurred in early January when algal activities were minimal.

Alkalinity, pH, Hardness (Tables 10-14)

These interrelated parameters were influenced by a variety of factors, including hydrological, climatic, and biological conditions. Average total alkalinity values in 1990 river samples were higher than those present in 1989, ranging from 108 to 244 mg/L. Lowest values occurred from late March through August. Unlike the drought years of 1988 and 1989, lowest values did not occur during periods of low flow. Like most years prior to 1987, high values frequently occurred during periods of low flow in November and December.

Carbonate alkalinity was consistently present in river samples during February, April, November, and December when river flows were relatively low. Values ranged from <1 mg/L during January and throughout most of the summer to 14 mg/L in November.

Values for pH in river samples remained relatively high in 1990, ranging from 7.9 to 9.4. Highest values occurred during February and April. As in previous years, highest levels accompanied increased photosynthetic activity.

Total hardness values in the upstream river were higher than those present in 1988 and 1989 and generally paralleled total alkalinity levels. The highest values (360-375 mg/L) occurred during early January and late July, while low values of approximately 170 mg/L occurred during April.

Hardness values in the discharge canal continued to be consistently higher during periods of station operation than upstream river values; a result of reconcentration in the blowdown. Total hardness levels in the discharge canal ranged from 262 mg/L in late February to 1,240 mg/L in early January. Levels downstream of the station were generally higher than upstream values during periods of station operation. In contrast to hardness, total alkalinity and pH values in the discharge canal were generally lower than river values when the station was operational. Discharge canal values for total alkalinity ranged from 40 to 228. Values for pH ranged from 7.4 to 8.7.

Phosphates (Tables 15 and 16)

Total phosphate concentrations in upstream river samples were generally lower than those observed in 1989. Ambient concentrations in the river ranged from 0.1 mg/L in November to 0.5 mg/L in February. Levels in the discharge canal were usually higher than those observed in the river. Values ranged from 0.2 to 7.0 mg/L.

Orthophosphate concentrations in river samples were frequently less than <0.1 mg/L from early April through July and from September through December. High values of 0.3 mg/L were present in January and early February. As in previous years, orthophosphate concentrations were lower than total phosphate levels, and as expected, the greatest differential between phosphate forms coincided with large plankton populations and the resultant uptake of orthophosphate.

Ammonia (Table 17)

Average ammonia concentrations in the river were somewhat lower than those observed in 1989 but remained above the 1983 to 1988 levels (Table 27). Although concentrations were consistently below detection limits (<0.1 mg/L as N) from April through early December, high concentrations of approximately 0.4 to 1.1 mg/L (as N) occurred in January and early February.

Nitrate (Table 18)

In contrast to the low flow years of 1988 and 1989, mean nitrate concentrations were extremely high, reaching their highest level since 1983, and were the third highest observed during the 1972 to 1990 period (Table 27). During the current year nitrate values in upstream river samples ranged from 1.4 to 17 mg/L (as N). Maximum levels (14-17 mg/L as N) were observed during a period of high river flow from late May through July. Concentrations in excess of 5 mg/L (as N) were consistently present from May through December.

Nitrate concentrations were frequently higher in the discharge canal than in river samples due to reconcentration in the blowdown. Maximum nitrate concentrations of 42 mg/L (as N) were observed in the discharge canal on March 21 and May 23.

Iron (Table 19)

Iron concentrations in the upstream river were higher than those observed during the past two years. Concentrations in upstream river samples ranged from 0.06 to 3.1 mg/L. The maximum value was observed in July. Low values of 0.06 to 0.08 mg/L occurred during January when river flow was low. As in previous years, high iron concentrations were usually observed in association with increased turbidity and suspended solids values, indicating that most of the iron present is in the suspended form rather than in solution. Iron levels continued to be consistently higher in the discharge canal throughout 1990. A maximum iron value of 11.0 mg/L was observed in the canal in May.

## Biological Conditions

Biochemical Oxygen Demand (Table 20)

Average five day biochemical oxygen demand ($BOD_5$) values were substantially lower than those present in 1988 and 1989, averaging 4.8 mg/L as compared to 9.6 and 10.3 mg/L in 1988 and 1989, respectively (Table 27). Levels in the river ranged from 2 to 17 mg/L. Because of minimal runoff, values observed during the winter and early spring continued to be low, ranging from 2 to 8 mg/L. Maximum BOD values, ranging from 12 to 17 mg/L, were observed in April, accompanied by large algal blooms. Levels remained low, ranging from 2 to 7 mg/L from late May through December.

*Coliform Organisms* (Tables 21 and 22)

Coliform determinations included enumeration of both fecal coliforms as well as specific determination of *Escherichia coli*.

Because of problems with interferences in coliform determination, total coliform organisms were discontinued and a new technique, the m-TEC MF procedure, which has been successfully used for the enumeration of thermotolerant *Escherichia coli* organisms, was instituted in October, 1989. The results of this procedure correlated well with the fecal coliform determinations.

In general, coliform values were higher than those present in 1988 and 1989, especially during the late May-September period when river flows were above normal. Maximum upstream fecal coliform and *E. coli* levels of 1,700 and 1,500 organisms/100 ml, respectively, were observed on August 23 at the beginning of a period of increasing runoff. Low values of less than 10 organisms/100 ml were frequently observed during periods of low river flow.

Both fecal coliform and *E. coli* levels were frequently higher in the discharge canal (Station 5) and in the mixing zone 140 feet downstream of the discharge (Station 3) than at upstream locations. Maximum fecal coliform and *E. coli* concentrations of 13,000 and 11,000 organisms/100 ml, respectively, were observed in samples from the discharge canal on October 3, collected during a moderate rain of approximately 0.3 inches. These high values resulted in yearly maximum levels of 1,500 organisms/100 ml of both *E. coli* and fecal coliform in the mixing zone at Station 3, as well as significant increases outside of the mixing zone.

Currently the NPDES permit for discharges from the Duanne Arnold Energy Center includes a limit on fecal coliform for the sewage treatment plant effluent, but does not require fecal coliform monitoring of the blowdown discharge. However, the *E. coli* and fecal coliform values of 690 and 720 organisms/ml, respectively, which were present at Station 4 on this date were in excess of the Iowa Water Quality Standards for Class A waters[20], which state that:

> From April 1 through October 31 fecal coliform content shall not exceed 200 organisms/100 ml, except when the waters are materially affected by surface runoff; but in no case shall fecal coliform levels downstream from a discharge which may contain human pathogens be more than 200 organisms/100 ml higher than the background level upstream from the discharge.

Since background coliform levels at this time were 200 organisms/100 ml or less, the downstream values were well in excess of this standard. The cause of these high fecal coliform values was not immediately determined, but runoff from the immediate area into the discharge canal was considered a probable cause. As a result, special studies were conducted by the University Hygienic Laboratory on December 20, 1990, which indicated relatively high fecal coliform and *E. coli* populations of 9,600 and 8,900 organisms/100 ml, respectively, in a portion of a roadside storm sewer that ultimately empties into the midsection of the station's discharge canal. Although flow in the storm sewer was minimal at the time of sampling, it is likely that substantial numbers of organisms could enter the discharge canal during periods of increased runoff from the adjacent lands into the storm sewer.

## ADDITIONAL STUDIES

In addition to the routine monthly studies a number of seasonal limnological and water quality investigations were conducted during 1990. The studies discussed here include additional chemical determinations, benthic studies, and Asiatic clam (*Corbicula*) and Zebra mussel (*Dreissena*) surveys and impingement determinations.

## Additional Chemical Determinations

Samples for additional chemical determinations were collected on April 11 and July 25 and analyzed for chlorides, sulfates, chromium, copper, lead, manganese, mercury, and zinc. In general, concentrations of all parameters in river samples fell within the expected ranges and were similar to those observed during the previous year.

Concentrations of most heavy metals in both the April and July, 1990 samples remained low. With the exception of manganese and zinc, heavy metal values were below detection limits in all river samples. Manganese was present in all river samples at concentrations ranging from 100 to 170 ug/L. Detectable levels of zinc (20 and 210 ug/L) were present in two river samples, the highest value occurring upstream of the station in April. No violations of water quality standards for heavy metals were observed.

Reconcentration of solids in the blowdown resulted in slight increases in copper in the July samples, and substantial increases in manganese and zinc in the April samples from the discharge canal. Relatively high sulfate concentrations were also observed in the discharge canal in April with lesser increases at the downstream locations. Higher sulfate levels are due in part to the addition of sulfuric acid for pH control in the cooling water. The results of additional chemical determinations are given in Table 23.

## Benthic Studies

The extremely high river stage present during the late spring and summer of 1990 disrupted the routine benthic studies. Attempts to collect Ponar dredge samples in the river upstream and downstream of the station on May 23 were unsuccessful, and Ponar samples were not collected until June 1. No macroinvertebrates were observed in either of the samples. Ponar dredge samples collected on November 15 were also free of benthic macroinvertebrates. These results are compatible with earlier studies that indicated the shifting sand and silt bottom supports a benthic community of very limited size and diversity. Only three organisms were found in the 1987 and 1989 Ponar dredge samples and no organisms were found in the 1988 samples.

Artificial substrates (Hester-Dendy) were placed at sampling locations upstream and downstream of the station on May 11 and July 20, but could not be retrieved due to the extremely high river flows. A third attempt was made to install substrates on September 21, and these substrates were finally retrieved on November 1 following a six week colonization period.

As in previous years, artificial substrate samples were characterized by greater numbers and species diversity than the natural substrate (Ponar dredge) samples. However, the diversity was somewhat lower than had been observed in the last two years. A total of 20 taxa were identified during the September-November sample period. Caddisfly (tricoptera) and midge (chironomid) larvae continued to be the most common organisms observed on the river substrates. The discharge canal samples continued to be dominated by the snail _Physa_ sp.

In general, there was little difference in the overall composition of the benthic populations between upstream and downstream locations, although differences between the four individual stations were present. The total numbers of organisms were substantially higher at the Lewis Access station than at the other three river locations, and both numbers and diversity were far lower in the discharge canal.

As in previous years, the artificial substrate studies indicate the Cedar River, both upstream and downstream of the Duane Arnold Energy Center, is capable of supporting a relatively diverse macroinvertebrate fauna in those limited areas where suitable bottom habitat is available. The results of the benthic studies are given in Table 24.

## Asiatic Clam and Zebra Mussel Surveys

In past years several power generation facilities have experienced problems with blockage of cooling water intake systems by large numbers of Asiatic clams (*Corbicula* sp.). Although this clam is common in portions of the Iowa reach of the Mississippi River, it is normally absent from areas with shifting sand/silt substrates such as occur in the Cedar River in the vicinity of the Duane Arnold Energy Center. *Corbicula* has not been collected from the Cedar River in the vicinity of the DAEC during the routine monitoring program, which was implemented in April of 1971. A single *Corbicula* was, however, collected in January of 1979 in the vicinity of Lewis Access, upstream of DAEC, by Hazelton personnel. Because *Corbicula* has been collected on one occasion from the Cedar River and is commonly found in power plant intakes on the Mississippi River, studies were implemented at the Duane Arnold Energy Center in 1981 to determine if the organism was present in the vicinity of the station or had established itself within the system. No *Corbicula* were collected during the 1981 to 1989 investigations. The Asiatic clam studies were continued during 1990. Samples were taken on May 23, June 1, and November 15, 1990. All of the surveys conducted during 1990 continued to be negative.

The Zebra mussel (*Dreissena polymorpha*) is a European form which was first found in the United States in 1988. Apparently this clam entered the St. Lawrence Seaway from ships that used fresh water from Europe as a ballast and then dumped the water when they reached the United States.[21]

The mussel has caused major problems in water intakes in Europe for many years and is now causing significant problems at Detroit Edison power plant intakes. The organisms tend to grow in clumps attached to a solid substrate and can rapidly clog intake structures, screens, and pipes. It is difficult to control chemically and must be removed mechanically.

The mussel is adapted to both river and lake habitats and does especially well in enriched waters which support large plankton populations that it utilizes as food. Unlike the Asiatic clam (Corbicula), it is capable of living in cold waters and does not require a silty substrate.

Currently this mussel has been found in the Detroit River and in Lakes Erie and St. Clair, but is likely to migrate into other Great Lakes and the Mississippi River drainage. Although it is impossible to make exact estimates, it will probably be found in these areas within five to eight years. If and when it does colonize these waters, problems with intake structures and power plants in the area are likely to occur.

As a result of these concerns, studies designed to detect the presence of the Zebra mussel were instituted in 1990. Sampling was performed at two locations in the discharge canal and two river locations, upstream and downstream of the station, using a mussel rake and/or Ponar dredge on June 1 and November 15. The intake bay, between the bar racks and the traveling screens, and the collection basin of the cooling tower were also sampled. In addition, visual inspections for Zebra mussel were also made in the cooling tower basin and along the river shoreline area. The shoreline and littoral area around the discharge structure at Pleasant Creek Lake was also inspected for the presence of the Zebra mussel. Concrete blocks were placed near the Pleasant Creek Lake discharge structure on March 21, 1990, to serve as artificial substrates for Zebra mussel colonization and were examined at intervals. None of the surveys conducted during 1990 revealed the presence of any of these mussels.

## Impingement Studies

The total numbers of fish impinged on the intake screens at the Duane Arnold Energy Center during 1990, as reported by Iowa Electric personnel, was far lower than in 1989 but still substantially higher than in years prior to 1988. Daily counts conducted by DAEC station personnel indicated a total of 1,981 fish were impinged during 1990. Highest impingement rates continued to occur during the winter and early spring period. During the months of January, February, and March 1,621 fish, or approximately 82% of the yearly impingement total, were removed from the trash baskets. Lowest impingement rates occurred from July through October when only 60 fish were removed from the trash baskets. As in 1989, the month with the highest impingement rate was March, when 1,261 fish were collected in the trash baskets. The results of the daily trash basket counts are given in Table 25.

## DISCUSSION AND CONCLUSIONS

The extended drought which characterized 1988 and 1989 ended in the spring of 1990 and resulted in significant changes in the hydrology and water quality of the Cedar River in the vicinity of the Duane Arnold Energy Center. The mean river flow of approximately 5,061 cfs was over five times that present in 1989 and slightly above the 1972 to 1990 mean of approximately 4,624 cfs.

Even during low flow periods the impact of station operation on the water quality of the Cedar River has generally been low, and as expected, these effects were minimal during the current year. In 1990 temperature increases in the discharge canal observed during sampling periods when the station was operational were as much as 18.0°C (32.4°F) above ambient river levels and averaged 7.2°C (13.0°F). However, downstream temperatures one-half mile below the plant averaged only 1.0°C (1.8°F) above ambient during periods of station operation and never exceeded upstream temperatures by more than 2.0°C (3.6°F). Temperature differentials ($\Delta T$) within the mixing zone (Station 3) were almost identical, never exceeding 3.0°C (5.4°F) and averaging only 1.0°C (1.8°F). On no occasion was an observed temperature differential in excess of the 3°C water quality standard.[20]

Several other parameters, i.e., dissolved solids, hardness, phosphate, nitrate, and iron continued to be present in substantially higher concentrations in the discharge canal during periods of station operation than at upstream locations, due to reconcentration in the blowdown discharge. Concentrations of these substances were also usually higher in the mixing zone (Station 3), but these increases were less evident than those present in 1988 and 1989.[18,19] Increases downstream of the mixing zone at Station 4 were substantially less and generally similar to those observed in 1989. A comparison of average values for the abovementioned parameters at upstream and downstream locations and in the discharge canal during periods of station operation are summarized in Table 26.

With the exception of a single sampling period, discussed earlier, when coliform levels at the downstream station were unusually high, there were no other incidents during the 1990 study where an exceedence of the applicable Iowa Water Quality Standards was observed which could possibly be attributed to activities at the Duane Arnold Energy Center. Some pH values in excess of the 9 Standard were present at both upstream and downstream locations in both February and April, but these high values were the result of algal photosynthesis and were unrelated to station operation.

Although station operation had little impact on river water quality, the effects of the markedly increased river flow following the extended drought were evident. The minimal precipitation which contributed to low levels of a number of parameters generally associated with runoff from agricultural lands in the basin persisted through early March, and as expected, mean levels of several substances which normally enter the river as a component of agricultural land runoff or associated with sediment continued to be low during the early part of 1990. This included turbidity, suspended solids, iron, coliform organisms, and nitrate. Levels of these parameters, especially nitrates, increased by March 21 following heavy rains which disrupted the extended dry period and resulted in marked increases in river discharge. Because of reduced soil moisture resulting from the extended drought, river stage declined rapidly following the initial early spring runoff. As a result, levels of the abovementioned parameters declined and remained low throughout April and early May. However, dissolved oxygen, pH, and BOD values increased as warmer temperatures and clear waters associated with the lower river flow contributed to the reestablishment of large algal populations and subsequent increases in photosynthetic activity.

The late May to early September period was characterized by extremely high river flows resulting in substantially higher turbidity, suspended solids, nitrate, iron, and fecal coliform values, and lower pH, dissolved oxygen, and BOD values than were present during the comparable period in 1988 or 1989. The effects of higher flows becomes evident when the average yearly values for nitrate and BOD are examined (Table 27), and are especially marked when relative loading values obtained by multiplying average concentrations by cumulative runoff are compared (Table 28).

Increased rainfall also resulted in a marked reversal in the trend towards low total hardness values which, in 1989, reached the lowest average level since the study was implemented in 1972, but rose in 1990 to the second highest value observed during the study period (Table 27). It appears that the low values observed in 1988 and 1989[18,19] were the result of the rapid downward movement of surface water through the dry unconsolidated surficial deposits into the shallow aquifers feeding the Cedar River. This rapid movement of water shortens its residence time in the surface deposits and shallow aquifer, and reduces the time available for the solubilization of calciferous materials. Obviously this trend was reversed in 1990.

As in previous years, the operation of the Duane Arnold Energy Center during 1990 appeared to have a minimal impact on the fish and other aquatic organisms in the Cedar River adjacent to the station. The benthic community of the Cedar River in the vicinity of the Duane Arnold Energy Center has been characterized by low diversity and productivity throughout the entire study period, and the paucity of organisms in bottom samples taken in 1990 is not unusual. This condition is unrelated to either station operation or poor water quality, however. The river bottom in the vicinity of the Duane Arnold Energy Center is characterized by a shifting sand and silt substrate, which is not conducive to the development of a diverse or productive benthic community. When artificial substrates (Hester-Dendy) have been placed in the Cedar River, however, they develop populations which are characterized by relatively high species diversity and many organisms indicative of relatively good water quality. Because of high flows the spring and summer artificial substrate studies could not be completed, but substrates installed upstream and downstream of the station during the fall of 1990 generally supported populations exhibiting similar composition and diversity, indicating that the impact of station operation on the benthic community of the Cedar River remains minimal.

During 1990 the total numbers of fish impinged on the intake screens at the Duane Arnold Energy Center was substantially less than present in 1989, but still above levels observed in prior years. Most of the impingement continued to occur during the January-March period when 1,621 fish, or approximately 82% of the 1990 yearly total of 1,981 were impinged. Increased impingement levels during the winter period appear to be related to the recirculation of warm water into the intake for deicing purposes, which attracts fish to the area that are subsequently impinged. Impingement rates were low during the remainder of the year, and since the problem was of short duration and was confined primarily to smaller fish, the impact on the fishery of the Cedar River was not considered to be significant.

# REFERENCES CITED


1. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Report, April 1971-April 1972. Duane Arnold Energy Center." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1972.

2. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Report, May 1972-April 1973. Duane Arnold Energy Center." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1973.

3. McDonald, D.B., "Cedar River Baseline Ecological Study Final Pre-Operational Report, May 1973-January 1974." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1974.

4. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Operational Report, January 1974-January 1975. Duane Arnold Energy Center." Report prepared for Iowa electric Light and Power Company by the University of Iowa, 1975.

5. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Report, January 1975-January 1976. Duane Arnold Energy Center." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1976.

6. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Report, January 1976-December 1976. Duane Arnold Energy Center." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1977.

7. McDonald, D.B., "Cedar River Baseline Ecological Study Annual Report, January 1977-December 1977. Duane Arnold Energy Center." Report prepared for Iowa Electric Light and Power Company by the University of Iowa, 1978.

8. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1978-December 1978." In: Reports of Environmental Monitoring Program, January 1978-December 1978, Iowa Electric Light and Power Company, 1979.

9. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1979-December 1979." Report prepared for Iowa Electric Light and Power Company by D.B. McDonald Research, Inc., Iowa City, May 1980.

10. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1980-December 1980." Report prepared for Iowa Electric Light and Power Company by D.B. McDonald Research, Inc., June 1981.

11. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1981-December 1981." Report prepared for Iowa Electric Light and Power Company, May 1982.

12. McDonald D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1982-December 1982." Report prepared for Iowa Electric Light and Power Company, May 1983.

13. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1983-December 1983." Report prepared for Iowa Electric Light and Power Company, March 1984.

14. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1984-December 1984." Report prepared for Iowa Electric Light and Power Company, April 1985.

15. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1985-December 1985." Report prepared for Iowa Electric Light and Power Company, May 1986.

16. McDonald D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1986-December 1986." Report prepared for Iowa Electric Light and Power Company, April 1987.

17. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1987-December 1987." Report prepared for Iowa Electric Light and Power Company, April 1988.

18. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1988-December 1988." Report prepared for Iowa Electric Light and Power Company, March 1989.

19. McDonald, D.B., "Duane Arnold Energy Center Cedar River Operational Ecological Study Annual Report, January 1989-December 1989." Report prepared for Iowa Electric Light and Power Company, March 1990.

20. State of Iowa, "Water Quality Standards." Chapter 15, 400, Iowa Administrative Code. State of Iowa, Des Moines, Iowa, March 1978.

21. O'Neill, C. and MacNeill, D., "Dreissena polymorpha. An Unwelcome Great Lakes Invader." Sea Grant Fact Sheet, Cornell University, New York, 1989

Table 1

Summary of Hydrological Conditions
Cedar River at Cedar Rapids*
1990

| Date | Mean Monthly Discharge cfs | Percent of 1951-1980 Median Discharge |
|---|---|---|
| January | 360 | 34 |
| February | 439 | 36 |
| March | 2,888 | 54 |
| April | 1,725 | 30 |
| May | 6,001 | 140 |
| June | 11,830 | 279 |
| July | 7,517 | 229 |
| August | 17,540 | 870 |
| September | 6,158 | 345 |
| October | 2,461 | 165 |
| November | 2,002 | 108 |
| December | 1,810 | 144 |

*Data obtained from U.S. Geological Survey record

Table 2

Temperature ($^{o}C$) Values from the Cedar River Near the Duane Arnold Energy Center During 1990

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 0.0 | 0.0 | 2.0 | 0.5 | 1.5 |
| Jan 24 | 0.5 | 0.5 | 11.5 | 1.5 | 2.0 |
| Feb 07 | 0.5 | 0.5 | 5.5 | 1.5 | 1.5 |
| Feb 21 | 0.5 | 0.5 | 6.5 | 2.5 | 2.5 |
| Mar 07 | 0.5 | 0.5 | 16.0 | 3.5 | 1.0 |
| Mar 21 | 5.5 | 6.0 | 23.5 | 6.5 | 7.5 |
| Apr 11 | 5.0 | 6.0 | 11.0 | 6.0 | 7.0 |
| Apr 25 | 22.0 | 22.0 | 28.0 | 22.0 | 23.0 |
| May 09 | 18.5 | 19.0 | 25.5 | 19.0 | 18.5 |
| May 23 | 14.5 | 14.5 | 26.0 | 15.0 | 15.0 |
| Jun 13 | 24.0 | 24.0 | 30.0 | 24.0 | 24.0 |
| Jun 27 | 25.5 | 25.0 | 32.0 | 25.0 | 25.0 |
| Jul 11 | 22.5 | 23.0 | 23.0 | 23.0 | 23.0 |
| Jul 25 | 23.0 | 23.5 | 29.0 | 23.5 | 23.5 |
| Aug 08 | 22.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| Aug 23 | 21.5 | 22.0 | 24.0 | 22.0 | 22.0 |
| Sep 05 | 23.0 | 24.5 | 26.0 | 25.0 | 25.0 |
| Sep 19 | 15.0 | 16.0 | 16.0 | 15.5 | 16.0 |
| Oct 03 | 17.5 | 17.0 | 19.5 | 17.0 | 17.0 |
| Oct 17 | 14.5 | 14.5 | 23.5 | 15.5 | 14.5 |
| Nov 01 | 12.5 | 13.5 | 24.0 | 14.5 | 14.0 |
| Nov 15 | 12.6 | 13.2 | 12.2 | 13.4 | 13.3 |
| Dec 05 | 0.0 | 0.0 | 1.5 | 0.5 | 1.5 |
| Dec 20 | 1.5 | 1.5 | 5.0 | 2.0 | 2.5 |

Table 3

Summary of Water Temperature Differentials and Station Output During Periods of Cedar River Sampling During 1990

| Date | $\Delta T$ (°C) Upstream River (Sta. 2) vs. Discharge. (Sta. 5) | $\Delta T$ (°C) Upstream River (Sta. 2) vs. Downstream River (Sta. 3) | $\Delta T$ (°C) Upstream River (Sta. 2) vs. Downstream River (Sta. 4) | Station Output (% Full Power) |
|---|---|---|---|---|
| Jan 10 | 2.0 | 0.5 | 1.5 | 100 |
| Jan 24 | 11.0 | 1.0 | 1.5 | 100 |
| Feb 07 | 5.0 | 1.0 | 1.0 | 100 |
| Feb 21 | 6.0 | 2.0 | 2.0 | 100 |
| Mar 07 | 15.5 | 3.0 | 1.0 | 100 |
| Mar 21 | 18.0 | 0.5 | 1.5 | 100 |
| Apr 11 | 5.0 | 0.0 | 1.0 | 99 |
| Apr 25 | 6.0 | 0.0 | 1.0 | 75 |
| May 09 | 6.5 | 0.0 | -0.5 | 83 |
| May 23 | 11.5 | 0.5 | 0.5 | 83 |
| Jun 13 | 6.0 | 0.0 | 0.0 | 83 |
| Jun 27 | 7.0 | 0.0 | 0.0 | 80 |
| Jul 11 | 0.0 | 0.0 | 0.0 | 0 |
| Jul 25 | 5.5 | 0.0 | 0.0 | 0 |
| Aug 08 | 0.0 | 0.0 | 0.0 | 0 |
| Aug 23 | 2.0 | 0.0 | 0.0 | 0 |
| Sep 05 | 1.5 | 0.5 | 0.5 | 0 |
| Sep 19 | 0.0 | -0.5 | 0.0 | 0 |
| Oct 03 | 2.5 | 0.0 | 0.0 | 52 |
| Oct 17 | 9.0 | 1.5 | 0.0 | 66 |
| Nov 01 | 10.5 | 1.0 | 0.5 | 99 |
| Nov 15 | -1.0 | 0.2 | 0.1 | 99 |
| Dec 05 | 1.5 | 0.5 | 1.5 | 98 |
| Dec 20 | 3.5 | 0.5 | 1.0 | 99 |

Table 4

Turbidity (NTU) Values from the Cedar River Near the Duane Arnold Energy Center During 1990

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 2 | 2 | 5 | 2 | 2 |
| Jan 24 | 2 | 3 | 4 | 2 | 9 |
| Feb 07 | 9 | 10 | 12 | 11 | 10 |
| Feb 21 | 5 | 5 | 5 | 6 | 7 |
| Mar 07 | 6 | 14 | 24 | 9 | 11 |
| Mar 21 | 37 | 37 | 160 | 40 | 36 |
| Apr 11 | 20 | 20 | 120 | 19 | 21 |
| Apr 25 | 34 | 31 | 72 | 38 | 34 |
| May 09 | 40 | 40 | 110 | 44 | 41 |
| May 23 | 140 | 160 | 1000 | 160 | 150 |
| Jun 13 | 59 | 57 | 140 | 62 | 64 |
| Jun 27 | 74 | 68 | 150 | 74 | 70 |
| Jul 11 | 74 | 72 | 58 | 70 | 70 |
| Jul 25 | 63 | 69 | 24 | 65 | 67 |
| Aug 08 | 50 | 52 | 39 | 50 | 46 |
| Aug 23 | 64 | 68 | 52 | 61 | 65 |
| Sep 05 | 43 | 44 | 35 | 43 | 44 |
| Sep 19 | 25 | 28 | 24 | 28 | 28 |
| Oct 03 | 18 | 44 | 330 | 78 | 37 |
| Oct 17 | 12 | 14 | 26 | 19 | 14 |
| Nov 01 | 6 | 10 | 28 | 10 | 10 |
| Nov 15 | 5 | 5 | 7 | 5 | 6 |
| Dec 05 | 6 | 8 | 10 | 7 | 8 |
| Dec 20 | 5 | 3 | 10 | 3 | 5 |

Table 5

Total Solids (mg/L) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 390 | 400 | 2100 | 440 | 430 |
| Jan 24 | 380 | 360 | 1000 | 400 | 420 |
| Feb 07 | 350 | 360 | 1900 | 500 | 410 |
| Feb 21 | 380 | 350 | 450 | 500 | 440 |
| Mar 07 | 380 | 370 | 1900 | 610 | 500 |
| Mar 21 | 390 | 380 | 1800 | 430 | 390 |
| Apr 11 | 340 | 340 | 700 | 290 | 310 |
| Apr 25 | 300 | 310 | 1400 | 320 | 310 |
| May 09 | 390 | 410 | 2000 | 460 | 390 |
| May 23 | 550 | 540 | 2500 | 580 | 560 |
| Jun 13 | 480 | 480 | 1400 | 490 | 490 |
| Jun 27 | 570 | 570 | 1300 | 650 | 580 |
| Jul 11 | 490 | 490 | 450 | 470 | 480 |
| Jul 25 | 490 | 490 | 370 | 480 | 480 |
| Aug 08 | 420 | 370 | 370 | 400 | 400 |
| Aug 23 | 370 | 380 | 350 | 360 | 360 |
| Sep 05 | 510 | 500 | 450 | 480 | 500 |
| Sep 19 | 380 | 410 | 400 | 400 | 400 |
| Oct 03 | 350 | 370 | 890 | 480 | 400 |
| Oct 17 | 350 | 360 | 1500 | 530 | 420 |
| Nov 01 | 360 | 350 | 1900 | 510 | 400 |
| Nov 15 | 390 | 400 | 460 | 410 | 420 |
| Dec 05 | 390 | 390 | 1200 | 400 | 410 |
| Dec 20 | 430 | 410 | 940 | 420 | 440 |

Table 6

Dissolved Solids (mg/L) values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 380 | 360 | 2100 | 400 | 400 |
| Jan 24 | 350 | 340 | 980 | 380 | 400 |
| Feb 07 | 330 | 330 | 1800 | 460 | 380 |
| Feb 21 | 350 | 310 | 430 | 460 | 390 |
| Mar 07 | 360 | 360 | 1800 | 560 | 470 |
| Mar 21 | 310 | 320 | 1400 | 350 | 330 |
| Apr 11 | 280 | 240 | 390 | 220 | 280 |
| Apr 25 | 220 | 220 | 1200 | 240 | 250 |
| May 09 | 300 | 280 | 1800 | 330 | 310 |
| May 23 | 350 | 340 | 1300 | 360 | 330 |
| Jun 13 | 360 | 350 | 1200 | 360 | 370 |
| Jun 27 | 380 | 370 | 970 | 430 | 390 |
| Jul 11 | 330 | 330 | 320 | 330 | 330 |
| Jul 25 | 340 | 330 | 330 | 350 | 330 |
| Aug 08 | 300 | 300 | 320 | 310 | 310 |
| Aug 23 | 240 | 240 | 260 | 250 | 250 |
| Sep 05 | 380 | 380 | 370 | 370 | 380 |
| Sep 19 | 350 | 310 | 330 | 330 | 330 |
| Oct 03 | 290 | 280 | 450 | 310 | 300 |
| Oct 17 | 310 | 290 | 1300 | 440 | 320 |
| Nov 01 | 320 | 320 | 1800 | 470 | 370 |
| Nov 15 | 360 | 350 | 420 | 380 | 360 |
| Dec 05 | 350 | 360 | 1200 | 370 | 380 |
| Dec 20 | 380 | 380 | 890 | 390 | 400 |

Table 7

Suspended Solids (mg/L) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | <1 | <1 | <1 | <1 | <1 |
| Jan 24 | 22 | 2 | 10 | 4 | 16 |
| Feb 07 | 9 | 12 | 17 | 12 | 14 |
| Feb 21 | 8 | 12 | 10 | 10 | 21 |
| Mar 07 | 11 | 15 | 30 | 19 | 16 |
| Mar 21 | 51 | 51 | 180 | 53 | 48 |
| Apr 11 | 48 | 45 | 280 | 45 | 48 |
| Apr 25 | 76 | 85 | 110 | 92 | 73 |
| May 09 | 82 | 91 | 160 | 86 | 89 |
| May 23 | 170 | 190 | 1100 | 190 | 180 |
| Jun 13 | 110 | 110 | 200 | 110 | 110 |
| Jun 27 | 110 | 100 | 200 | 120 | 100 |
| Jul 11 | 120 | 120 | 93 | 110 | 120 |
| Jul 25 | 130 | 120 | 24 | 110 | 110 |
| Aug 08 | 70 | 68 | 53 | 69 | 65 |
| Aug 23 | 84 | 92 | 63 | 86 | 93 |
| Sep 05 | 81 | 81 | 53 | 77 | 80 |
| Sep 19 | 54 | 58 | 50 | 63 | 68 |
| Oct 03 | 40 | 86 | 400 | 110 | 64 |
| Oct 17 | 33 | 36 | 47 | 50 | 39 |
| Nov 01 | 24 | 26 | 41 | 25 | 26 |
| Nov 15 | 10 | 13 | 11 | 13 | 18 |
| Dec 05 | 13 | 13 | 12 | 13 | 13 |
| Dec 20 | 12 | 9 | 8 | 8 | 9 |

Table 8

Dissolved Oxygen (mg/L) Values

| Date 1990 | Sampling Locations | | | | |
|---|---|---|---|---|---|
| | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 11.0 | 11.5 | 11.0 | 11.6 | 12.5 |
| Jan 24 | 13.4 | 16.0 | 11.5 | 15.1 | 15.0 |
| Feb 07 | 14.9 | 15.4 | 12.6 | 14.8 | 16.8 |
| Feb 21 | 18.2 | 19.0 | 11.6 | 17.8 | 18.1 |
| Mar 07 | 20.0 | 20.0 | 12.0 | 20.0 | 20.0 |
| Mar 21 | 11.0 | 11.0 | 7.6 | 10.8 | 10.9 |
| Apr 11 | 14.2 | 15.2 | 12.5 | 15.9 | 14.9 |
| Apr 25 | 10.6 | 11.6 | 7.0 | 12.2 | 13.2 |
| May 09 | 9.1 | 9.0 | 6.2 | 9.2 | 9.4 |
| May 23 | 8.4 | 8.4 | 6.0 | 8.2 | 8.2 |
| Jun 13 | 7.5 | 7.5 | 6.4 | 7.5 | 7.4 |
| Jun 27 | 6.9 | 6.9 | 7.1 | 7.0 | 7.1 |
| Jul 11 | 8.1 | 8.9 | 8.8 | 9.0 | 9.0 |
| Jul 25 | 7.9 | 7.6 | 6.9 | 8.0 | 8.1 |
| Aug 08 | 8.0 | 8.6 | 10.2 | 8.6 | 8.6 |
| Aug 23 | 7.2 | 7.0 | 7.2 | 7.0 | 7.0 |
| Sep 05 | 7.9 | 8.2 | 7.9 | 8.3 | 8.4 |
| Sep 19 | 10.2 | 10.4 | 11.1 | 10.2 | 10.4 |
| Oct 03 | 10.1 | 9.4 | 8.0 | 9.1 | 9.4 |
| Oct 17 | 12.5 | 13.3 | 7.1 | 12.3 | 13.2 |
| Nov 01 | 12.1 | 14.1 | 7.2 | 13.6 | 15.0 |
| Nov 15 | 12.6 | 13.2 | 12.2 | 13.4 | 13.3 |
| Dec 05 | 14.6 | 14.4 | 10.9 | 15.2 | 15.1 |
| Dec 20 | 14.4 | 14.4 | 11.5 | 13.8 | 13.8 |

Table 9

Carbon Dioxide (mg/L) Values

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 5 | 4 | 2 | 5 | 3 |
| Jan 24 | 3 | 2 | * | 3 | 3 |
| Feb 07 | <1 | <1 | * | <1 | <1 |
| Feb 21 | <1 | <1 | 3 | <1 | <1 |
| Mar 07 | <1 | <1 | * | <1 | <1 |
| Mar 21 | <1 | <1 | * | 3 | 3 |
| Apr 11 | <1 | <1 | <1 | <1 | <1 |
| Apr 25 | <1 | <1 | * | <1 | <1 |
| May 09 | <1 | <1 | * | <1 | <1 |
| May 23 | 4 | 3 | * | 2 | 3 |
| Jun 13 | 1 | 1 | 2 | 1 | 1 |
| Jun 27 | 2 | 2 | * | 2 | 2 |
| Jul 11 | <1 | <1 | <1 | <1 | <1 |
| Jul 25 | 2 | 2 | 2 | 2 | 2 |
| Aug 08 | 2 | 2 | 2 | 2 | 2 |
| Aug 23 | 3 | 3 | 3 | 3 | 3 |
| Sep 05 | 2 | <1 | 1 | <1 | <1 |
| Sep 19 | 2 | 2 | <1 | 2 | 1 |
| Oct 03 | <2 | <1 | 2 | <1 | <1 |
| Oct 17 | <1 | <1 | * | <1 | <1 |
| Nov 01 | <1 | <1 | * | <1 | <1 |
| Nov 15 | <1 | <1 | 2 | <1 | <1 |
| Dec 05 | <1 | <1 | * | <1 | <1 |
| Dec 20 | <1 | <1 | * | <1 | <1 |

*Unable to calculate

Table 10

Total Alkalinity (mg/L - $CaCO_3$) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 210 | 210 | 96 | 218 | 206 |
| Jan 24 | 210 | 204 | 40 | 190 | 202 |
| Feb 07 | 196 | 198 | 100 | 186 | 188 |
| Feb 21 | 224 | 200 | 28 | 202 | 200 |
| Mar 07 | 204 | 206 | 108 | 186 | 194 |
| Mar 21 | 140 | 144 | 96 | 134 | 138 |
| Apr 11 | 146 | 142 | 146 | 142 | 140 |
| Apr 25 | 110 | 108 | 96 | 108 | 108 |
| May 09 | 138 | 138 | 86 | 134 | 132 |
| May 23 | 138 | 134 | 88 | 132 | 130 |
| Jun 13 | 180 | 180 | 90 | 180 | 180 |
| Jun 27 | 174 | 170 | 126 | 168 | 168 |
| Jul 11 | 180 | 180 | 184 | 180 | 180 |
| Jul 25 | 182 | 182 | 170 | 178 | 166 |
| Aug 08 | 174 | 166 | 172 | 168 | 166 |
| Aug 23 | 144 | 146 | 150 | 144 | 142 |
| Sep 05 | 232 | 226 | 228 | 228 | 222 |
| Sep 19 | 206 | 208 | 206 | 202 | 208 |
| Oct 03 | 196 | 196 | 174 | 184 | 190 |
| Oct 17 | 210 | 204 | 100 | 200 | 202 |
| Nov 01 | 210 | 196 | 102 | 202 | 212 |
| Nov 15 | 228 | 232 | 224 | 230 | 226 |
| Dec 05 | 244 | 240 | 140 | 230 | 224 |
| Dec 20 | 232 | 230 | 184 | 238 | 226 |

Table 11

Carbonate Alkalinity (mg/L - $CaCO_3$) Values

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | <1 | <1 | <1 | <1 | <1 |
| Jan 24 | <1 | <1 | <1 | <1 | <1 |
| Feb 07 | 6 | 6 | <1 | 8 | 4 |
| Feb 21 | 8 | 8 | <1 | 10 | 8 |
| Mar 07 | 8 | 10 | <1 | 4 | 8 |
| Mar 21 | <1 | <1 | <1 | <1 | <1 |
| Apr 11 | 6 | 8 | 6 | 8 | 8 |
| Apr 25 | 4 | 6 | <1 | 8 | 8 |
| May 09 | 2 | 2 | <1 | 2 | 2 |
| May 23 | <1 | <1 | <1 | <1 | <1 |
| Jun 13 | <1 | <1 | <1 | <1 | <1 |
| Jun 27 | <1 | <1 | 2 | <1 | <1 |
| Jul 11 | 6 | 6 | 2 | 4 | 4 |
| Jul 25 | <1 | <1 | <1 | <1 | <1 |
| Aug 08 | <1 | <1 | <1 | <1 | <1 |
| Aug 23 | <1 | <1 | <1 | <1 | <1 |
| Sep 05 | <1 | 4 | 14 | 6 | 6 |
| Sep 19 | <1 | <1 | 8 | <1 | 2 |
| Oct 03 | 2 | 2 | <1 | 2 | 4 |
| Oct 17 | 4 | 4 | <1 | 3 | 4 |
| Nov 01 | 8 | 8 | 0 | 8 | 14 |
| Nov 15 | 10 | 10 | <1 | 4 | 14 |
| Dec 05 | 6 | 6 | <1 | 6 | 8 |
| Dec 20 | 4 | 6 | <1 | 8 | 12 |

Table 12

Units of pH from the Cedar River

| Date 1990 | Sampling Locations: Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| Jan 10 | 8.1 | 8.2 | 8.0 | 8.1 | 8.2 |
| Jan 24 | 8.3 | 8.4 | 7.7 | 8.3 | 8.3 |
| Feb 07 | 8.7 | 8.8 | 8.7 | 8.8 | 8.2 |
| Feb 21 | 8.9 | 9.1 | 7.6 | 9.0 | 9.0 |
| Mar 07 | 8.8 | 8.8 | 7.4 | 8.8 | 8.4 |
| Mar 21 | 8.0 | 8.0 | 8.0 | 8.0 | 8.1 |
| Apr 11 | 8.8 | 8.9 | 8.6 | 8.9 | 8.9 |
| Apr 25 | 9.2 | 9.3 | 8.2 | 9.4 | 9.4 |
| May 09 | 8.5 | 8.6 | 7.9 | 8.6 | 8.7 |
| May 23 | 7.9 | 8.0 | 7.7 | 8.0 | 8.0 |
| Jun 13 | 8.5 | 8.4 | 7.8 | 8.5 | 8.4 |
| Jun 27 | 8.2 | 8.1 | 8.6 | 8.1 | 8.1 |
| Jul 11 | 8.7 | 8.7 | 8.6 | 8.7 | 8.7 |
| Jul 25 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 |
| Aug 08 | 8.2 | 8.1 | 8.2 | 8.1 | 8.1 |
| Aug 23 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Sep 05 | 8.3 | 8.4 | 8.7 | 8.5 | 8.4 |
| Sep 19 | 8.4 | 8.4 | 8.6 | 8.4 | 8.5 |
| Oct 03 | 8.5 | 8.5 | 8.3 | 8.4 | 8.4 |
| Oct 17 | 8.9 | 8.9 | 8.0 | 8.9 | 8.9 |
| Nov 01 | 8.7 | 8.7 | 7.7 | 8.7 | 8.8 |
| Nov 15 | 8.5 | 8.6 | 8.3 | 8.5 | 8.6 |
| Dec 05 | 8.6 | 8.6 | 7.6 | 8.7 | 8.7 |
| Dec 20 | 8.5 | 8.5 | 7.8 | 8.5 | 8.5 |

Table 13

Total Hardness (mg/L - $CaCO_3$) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 310 | 375 | 1240 | 325 | 345 |
| Jan 24 | 274 | 270 | 566 | 294 | 300 |
| Feb 07 | 251 | 245 | 1130 | 265 | 295 |
| Feb 21 | 294 | 274 | 262 | 390 | 316 |
| Mar 07 | 280 | 265 | 1080 | 390 | 320 |
| Mar 21 | 258 | 260 | 1040 | 268 | 284 |
| Apr 11 | 215 | 210 | 310 | 315 | 235 |
| Apr 25 | 170 | 170 | 740 | 175 | 195 |
| May 09 | 230 | 230 | 1170 | 275 | 260 |
| May 23 | 280 | 270 | 1080 | 280 | 295 |
| Jun 13 | 290 | 265 | 765 | 290 | 300 |
| Jun 27 | 310 | 300 | 670 | 300 | 305 |
| Jul 11 | 285 | 280 | 285 | 275 | 295 |
| Jul 25 | * | 360 | 340 | 350 | 370 |
| Aug 08 | 230 | 240 | 240 | 240 | 240 |
| Aug 23 | 205 | 215 | 220 | 210 | 210 |
| Sep 05 | 315 | 320 | 310 | 330 | 315 |
| Sep 19 | 285 | 280 | 285 | 295 | 280 |
| Oct 03 | 314 | 288 | 345 | 284 | 310 |
| Oct 17 | 285 | 285 | 870 | 355 | 295 |
| Nov 01 | 290 | 285 | 1180 | 370 | 308 |
| Nov 15 | 305 | 315 | 335 | 320 | 310 |
| Dec 05 | 290 | 310 | 810 | 310 | 330 |
| Dec 20 | 350 | 355 | 655 | 355 | 365 |

*Laboratory accident

Table 14

Calcium Hardness (mg/L - $CaCO_3$)

| Date 1990 | Sampling Locations<br>Upstream of Plant<br>1 | Upstream of Plant Intake<br>2 | Discharge Canal<br>5 | 140 Feet Downstream of Discharge<br>3 | 1/2 Mile Downstream from Plant<br>4 |
|---|---|---|---|---|---|
| Jan 10 | 180 | 190 | 710 | 190 | 220 |
| Jan 24 | 168 | 174 | 330 | 196 | 202 |
| Feb 07 | 150 | 160 | 711 | 205 | 170 |
| Feb 21 | 174 | 186 | 152 | 222 | 200 |
| Mar 07 | 171 | 175 | 708 | 236 | 211 |
| Mar 21 | 160 | 170 | 690 | 180 | 180 |
| Apr 11 | 120 | 120 | 190 | 120 | 130 |
| Apr 25 | 95 | 90 | 390 | 95 | 95 |
| May 09 | 140 | 135 | 730 | 170 | 165 |
| May 23 | 185 | 180 | 660 | 205 | 180 |
| Jun 13 | 195 | 215 | 510 | 195 | 200 |
| Jun 27 | 210 | 210 | 460 | 220 | 210 |
| Jul 11 | 175 | 175 | 190 | 180 | 170 |
| Jul 25 | 210 | 210 | 190 | 230 | 220 |
| Aug 08 | 160 | 160 | 160 | 140 | 150 |
| Aug 23 | 145 | 140 | 150 | 135 | 145 |
| Sep 05 | 215 | 215 | 220 | 220 | 220 |
| Sep 19 | 190 | 180 | 180 | 190 | 180 |
| Oct 03 | 172 | 178 | 230 | 192 | 180 |
| Oct 17 | 180 | 215 | 571 | 220 | 195 |
| Nov 01 | 180 | 170 | 750 | 240 | 240 |
| Nov 15 | 195 | 200 | 225 | 210 | 200 |
| Dec 05 | 200 | 200 | 520 | 200 | 200 |
| Dec 20 | 215 | 205 | 440 | 220 | 220 |

Table 15

Total Phosphorus (mg/L-P) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 0.3 | 0.3 | 1.3 | 0.3 | 0.3 |
| Jan 24 | 0.3 | 0.3 | 0.9 | 0.4 | 0.4 |
| Feb 07 | 0.5 | 0.4 | 1.4 | 0.5 | 0.5 |
| Feb 21 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 |
| Mar 07 | 0.4 | 0.3 | 1.2 | 0.5 | 0.4 |
| Mar 21 | 0.4 | 0.4 | 1.9 | 0.4 | 0.4 |
| Apr 11 | 0.2 | 0.2 | 0.7 | 0.2 | 0.2 |
| Apr 25 | 0.2 | 0.3 | 1.2 | 0.3 | 0.3 |
| May 09 | 0.3 | 0.2 | 1.3 | 0.3 | 0.2 |
| May 23 | 0.4 | 0.4 | 2.8 | 0.5 | 0.4 |
| Jun 13 | 0.3 | 0.3 | 0.7 | 0.3 | 0.3 |
| Jun 27 | 0.3 | 0.3 | 7.0 | 0.3 | 0.3 |
| Jul 11 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 |
| Jul 25 | 0.3 | 0.3 | 2.0 | 0.3 | 0.4 |
| Aug 08 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Aug 23 | 0.5 | 0.3 | 0.3 | 0.4 | 0.4 |
| Sep 05 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Sep 19 | 0.2 | 0.2 | 0.6 | 0.3 | 0.2 |
| Oct 03 | 0.2 | 0.2 | 0.9 | 0.3 | 0.2 |
| Oct 17 | 0.2 | 0.1 | 2.0 | 0.4 | 0.2 |
| Nov 01 | 0.3 | 0.2 | 1.5 | 0.3 | 0.2 |
| Nov 15 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 |
| Dec 05 | 0.2 | 0.2 | 0.8 | 0.2 | 0.2 |
| Dec 20 | 0.1 | 0.2 | 0.7 | 0.2 | 0.2 |

Table 16

Soluble Orthophosphate (mg/L-P) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| Jan 10 | 0.3 | 0.3 | 0.9 | 0.3 | 0.3 |
| Jan 24 | 0.3 | 0.3 | 0.5 | 0.3 | 0.3 |
| Feb 07 | 0.3 | 0.3 | 0.9 | 0.3 | 0.3 |
| Feb 21 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Mar 07 | 0.1 | 0.1 | 0.5 | 0.2 | 0.1 |
| Mar 21 | 0.2 | 0.2 | 0.7 | 0.2 | 0.2 |
| Apr 11 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Apr 25 | <0.1 | <0.1 | 0.2 | <0.1 | <0.1 |
| May 09 | <0.1 | <0.1 | 0.3 | <0.1 | <0.1 |
| May 23 | 0.1 | 0.1 | 0.4 | 0.1 | 0.1 |
| Jun 13 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 |
| Jun 27 | 0.2 | 0.2 | 0.4 | 0.2 | 0.2 |
| Jul 11 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Jul 25 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Aug 08 | 0.2 | 0.2 | 0.4 | 0.2 | 0.2 |
| Aug 23 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Sep 05 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 |
| Sep 19 | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| Oct 03 | <0.1 | <0.1 | 0.2 | <0.1 | <0.1 |
| Oct 17 | <0.1 | <0.1 | 0.5 | <0.1 | <0.1 |
| Nov 01 | <0.1 | <0.1 | 0.5 | <0.1 | <0.1 |
| Nov 15 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Dec 05 | <0.1 | <0.1 | 0.3 | <0.1 | <0.1 |
| Dec 20 | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 |

Table 17

Ammonia (mg/L-N) Values

| Date 1990 | Sampling Locations: Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| Jan 10 | 1.1 | 1.1 | 0.3 | 1.1 | 1.1 |
| Jan 24 | 0.7 | 0.7 | 0.2 | 0.6 | 0.6 |
| Feb 07 | 0.4 | 0.4 | 0.2 | 0.4 | 0.4 |
| Feb 21 | <0.1 | <0.1 | 0.2 | <0.1 | <0.1 |
| Mar 07 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Mar 21 | 0.3 | 0.4 | 0.2 | 0.4 | 0.4 |
| Apr 11 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Apr 25 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| May 09 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| May 23 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Jun 13 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Jun 27 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Jul 11 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Jul 25 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Aug 08 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Aug 23 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Sep 05 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Sep 19 | <0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| Oct 03 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Oct 17 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Nov 01 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Nov 15 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Dec 05 | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| Dec 20 | 0.4 | 0.1 | 0.2 | 0.2 | 0.2 |

Table 18

Nitrate (mg/L-N) Values

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 3.6 | 3.6 | 14.0 | 4.0 | 4.2 |
| Jan 24 | 3.4 | 3.4 | 6.6 | 3.9 | 4.0 |
| Feb 07 | 3.3 | 3.3 | 13.0 | 4.1 | 3.7 |
| Feb 21 | 3.3 | 3.4 | 2.2 | 4.4 | 3.8 |
| Mar 07 | 2.5 | 2.5 | 9.2 | 4.2 | 3.1 |
| Mar 21 | 12.0 | 11.0 | 42.0 | 12.0 | 12.0 |
| Apr 11 | 2.3 | 2.3 | 3.0 | 2.3 | 2.4 |
| Apr 25 | 1.4 | 1.4 | 5.3 | 1.3 | 1.4 |
| May 09 | 7.6 | 7.6 | 30.0 | 8.0 | 7.8 |
| May 23 | 17.0 | 16.0 | 42.0 | 16.0 | 16.0 |
| Jun 13 | 11.0 | 11.0 | 25.0 | 10.0 | 11.0 |
| Jun 27 | 17.0 | 17.0 | 35.0 | 17.0 | 16.0 |
| Jul 11 | 9.6 | 9.6 | 9.1 | 9.4 | 9.5 |
| Jul 25 | 14.0 | 13.0 | 11.0 | 13.0 | 13.0 |
| Aug 08 | 9.0 | 9.0 | 8.5 | 9.0 | 9.1 |
| Aug 23 | 7.0 | 6.9 | 6.3 | 6.9 | 6.9 |
| Sep 05 | 9.7 | 9.8 | 8.4 | 9.7 | 9.7 |
| Sep 19 | 6.4 | 6.3 | 5.4 | 6.2 | 6.4 |
| Oct 03 | 5.4 | 5.3 | 4.5 | 5.2 | 5.3 |
| Oct 17 | 5.8 | 5.7 | 16.0 | 6.8 | 5.9 |
| Nov 01 | 5.3 | 5.2 | 19.0 | 6.6 | 5.5 |
| Nov 15 | 6.7 | 6.7 | 7.0 | 7.0 | 6.9 |
| Dec 05 | 5.3 | 5.3 | 11.0 | 5.4 | 5.6 |
| Dec 20 | 7.6 | 7.6 | 8.8 | 7.7 | 7.9 |

Table 19

Total Iron (mg/L) Values

| | Sampling Locations | | | | |
|---|---|---|---|---|---|
| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
| Jan 10 | 0.08 | 0.07 | 0.44 | 0.07 | 0.08 |
| Jan 24 | 0.08 | 0.06 | 0.52 | 0.08 | 0.26 |
| Feb 07 | 0.22 | 0.21 | 0.45 | 0.18 | 0.24 |
| Feb 21 | 0.16 | 0.08 | 0.22 | 0.19 | 0.07 |
| Mar 07 | 0.09 | 0.10 | 0.46 | 0.20 | 0.16 |
| Mar 21 | 0.72 | 0.68 | 2.90 | 0.74 | 0.67 |
| Apr 11 | 0.28 | 0.35 | 2.20 | 0.29 | 0.29 |
| Apr 25 | 0.17 | 0.17 | 0.64 | 0.20 | 0.18 |
| May 09 | 0.21 | 0.22 | 1.30 | 0.34 | 0.27 |
| May 23 | 1.40 | 1.80 | 11.0 | 1.80 | 1.50 |
| Jun 13 | 0.68 | 0.70 | 2.50 | 0.79 | 0.79 |
| Jun 27 | 1.20 | 1.20 | 2.70 | 1.20 | 1.10 |
| Jul 11 | 0.62 | 0.68 | 0.66 | 0.65 | 0.67 |
| Jul 25 | 3.10 | 3.00 | 0.14 | 2.80 | 2.70 |
| Aug 08 | 0.72 | 0.78 | 0.59 | 0.68 | 0.75 |
| Aug 23 | 1.50 | 1.50 | 1.10 | 1.50 | 1.30 |
| Sep 05 | 0.67 | 0.65 | 0.53 | 0.68 | 0.69 |
| Sep 19 | 0.48 | 0.63 | 0.70 | 0.73 | 0.50 |
| Oct 03 | 0.23 | 0.51 | 2.40 | 0.72 | 0.47 |
| Oct 17 | 0.17 | 0.18 | 0.74 | 0.47 | 0.19 |
| Nov 01 | 0.10 | 0.14 | 0.54 | 0.14 | 0.11 |
| Nov 15 | 0.13 | 0.16 | 0.24 | 0.16 | 0.20 |
| Dec 05 | 0.13 | 0.13 | 0.49 | 0.15 | 0.14 |
| Dec 20 | 0.14 | 0.15 | 0.36 | 0.12 | 0.15 |

Table 20

Biochemical Oxygen Demand (5-day in mg/L) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| Jan 10 | 2 | 2 | 3 | 2 | 3 |
| Jan 24 | 2 | 3 | 11 | 3 | 3 |
| Feb 07 | 6 | 7 | 6 | 7 | 7 |
| Feb 21 | 6 | 7 | 2 | 8 | 7 |
| Mar 07 | 6 | 6 | 12 | 7 | 7 |
| Mar 21 | 3 | 4 | 8 | 4 | 4 |
| Apr 11 | 12 | 12 | 23 | 12 | 12 |
| Apr 25 | 16 | 15 | 27 | 17 | 17 |
| May 09 | 9 | 10 | 22 | 10 | 10 |
| May 23 | 3 | 3 | 9 | 3 | 3 |
| Jun 13 | 4 | 3 | 12 | 4 | 4 |
| Jun 27 | 2 | 2 | 3 | 2 | 2 |
| Jul 11 | 7 | 7 | 7 | 8 | 7 |
| Jul 25 | 2 | 2 | 2 | 2 | 2 |
| Aug 08 | 2 | 2 | 1 | 2 | 2 |
| Aug 23 | 3 | 3 | 2 | 3 | 2 |
| Sep 05 | 3 | 3 | 2 | 3 | 3 |
| Sep 19 | 6 | 6 | 6 | 4 | 6 |
| Oct 03 | 5 | 5 | 8 | 5 | 6 |
| Oct 17 | 4 | 5 | 13 | 5 | 5 |
| Nov 01 | 4 | 5 | 14 | 6 | 5 |
| Nov 15 | 2 | 2 | 2 | 2 | 2 |
| Dec 05 | 3 | 4 | 3 | 4 | 4 |
| Dec 20 | 2 | 2 | 1 | 2 | 2 |

Table 21

Coliform Bacteria (Fecal Organisms/100 ml) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 10 | 30 | 160 | <10 | <10 |
| Jan 24 | <10 | <10 | 320 | <10 | 10 |
| Feb 07 | 30 | 50 | 50 | 20 | 40 |
| Feb 21 | <10 | <10 | 30 | 10 | <10 |
| Mar 07 | <10 | <10 | <10 | <10 | <10 |
| Mar 21 | 90 | 70 | 1200 | 200 | 80 |
| Apr 11 | 10 | 10 | * | <10 | 10 |
| Apr 25 | <10 | 10 | * | 10 | <10 |
| May 09 | 50 | 20 | 60 | 60 | 10 |
| May 23 | 660 | 640 | 90 | 730 | 510 |
| Jun 13 | 20 | 60 | * | 50 | 70 |
| Jun 27 | 390 | 400 | * | 620 | 440 |
| Jul 11 | 210 | 270 | 290 | 340 | 330 |
| Jul 25 | 460 | 460 | 810 | 430 | 330 |
| Aug 08 | 190 | 160 | 190 | 210 | 210 |
| Aug 23 | 1700 | 1200 | 800 | 1000 | 800 |
| Sep 05 | 810 | 1100 | 530 | 1100 | 910 |
| Sep 19 | 240 | 150 | 100 | 170 | 170 |
| Oct 03 | 130 | 200 | 13000 | 1500 | 720 |
| Oct 17 | 40 | 40 | 150 | 30 | 10 |
| Nov 01 | <10 | <10 | 160 | 20 | 10 |
| Nov 15 | 10 | 20 | 60 | 10 | 40 |
| Dec 05 | 40 | 20 | 290 | 30 | <10 |
| Dec 20 | 210 | 30 | 1300 | 50 | 30 |

*Unable to quantify

Table 22

Coliform Bacteria (*E. coli*/100 ml) Values

| Date 1990 | Upstream of Plant 1 | Upstream of Plant Intake 2 | Discharge Canal 5 | 140 Feet Downstream of Discharge 3 | 1/2 Mile Downstream from Plant 4 |
|---|---|---|---|---|---|
| | Sampling Locations | | | | |
| Jan 10 | 30 | 20 | 120 | 10 | 10 |
| Jan 24 | <10 | 10 | 350 | <10 | 10 |
| Feb 07 | 30 | 30 | 50 | 20 | 60 |
| Feb 21 | <10 | <10 | 50 | <10 | 10 |
| Mar 07 | <10 | <10 | <10 | <10 | <10 |
| Mar 21 | 100 | 30 | 300 | 60 | 50 |
| Apr 11 | <10 | <10 | 30 | 10 | <10 |
| Apr 25 | 10 | <10 | 50 | 10 | <10 |
| May 09 | 30 | 20 | 60 | 10 | <10 |
| May 23 | 540 | 670 | 120 | 490 | 570 |
| Jun 13 | 40 | 80 | 100 | 60 | 50 |
| Jun 27 | 460 | 410 | 800 | 460 | 570 |
| Jul 11 | 240 | 320 | 310 | 230 | 200 |
| Jul 25 | 370 | 430 | 730 | 310 | 390 |
| Aug 08 | 230 | 190 | 280 | 300 | 260 |
| Aug 23 | 1000 | 1500 | 1000 | 1200 | 800 |
| Sep 05 | 980 | 940 | 520 | 930 | 770 |
| Sep 19 | 170 | 180 | 100 | 220 | 230 |
| Oct 03 | 130 | 180 | 11000 | 1500 | 690 |
| Oct 17 | 20 | 20 | 90 | 20 | 20 |
| Nov 01 | <10 | 10 | 50 | 20 | <10 |
| Nov 15 | 10 | 30 | 60 | 10 | <10 |
| Dec 05 | 10 | 10 | 180 | 10 | <10 |
| Dec 20 | 60 | 10 | 890 | 30 | 40 |

Table 23

Additional Chemical Analysis - 1990

| Station | $Cl^-$ (mg/L) | $SO_4^{-2}$ (mg/L) | Metals (ug/L) Cr | Cu | Pb | Mn | Hg | Zn |
|---|---|---|---|---|---|---|---|---|
| **April 11** | | | | | | | | |
| 1. Lewis Access | 32 | 56 | <20 | <10 | <10 | 100 | <1 | <20 |
| 2. Upstream DAEC | 31 | 53 | <20 | <10 | <10 | 130 | <1 | 210 |
| 3. Downstream DAEC | 32 | 63 | <20 | <10 | <10 | 110 | <1 | <20 |
| 4. One-half mile below plant | 34 | 76 | <20 | <10 | <10 | 110 | <1 | <20 |
| 5. Discharge Canal | 47 | 160 | <20 | <10 | <10 | 410 | <1 | 380 |
| **July 25** | | | | | | | | |
| 1. Lewis Access | 25 | 33 | <20 | <10 | <10 | 170 | <1 | <20 |
| 2. Upstream DAEC | 24 | 32 | <20 | <10 | <10 | 160 | <1 | <20 |
| 3. Downstream DAEC | 23 | 36 | <20 | <10 | <10 | 160 | <1 | <20 |
| 4. One-half mile below plant | 24 | 36 | <20 | <10 | <10 | 150 | <1 | 20 |
| 5. Discharge Canal | 23 | 41 | <20 | 40 | <10 | 30 | <1 | <20 |

Table 24

Benthic Macroinvertebrates Collected from the Cedar River and Discharge Canal Near Duane Arnold Energy Center
21 September - 1 November 1990

| Taxon | Lewis Access | U/S DAEC | Discharge Canal | D/S DAEC | ½ mi. below plant |
|---|---|---|---|---|---|
| Arthropoda | | | | | |
| Insecta | | | | | |
| Coleoptera | | | | | |
| Elmidae | | | | | |
| Optioservus sp. | | 1 | | 1 | |
| Diptera | | | | | |
| Chironomidae (larvae) | 187 | 13 | | 178 | 59 |
| Simuliidae | | | | | |
| Simulium sp. | 160 | 7 | | 10 | 26 |
| Athericidae | | | | | |
| Atherix sp. | 4 | 1 | | 4 | 6 |
| Ephemeroptera | | | | | |
| Baetidae | | | | | |
| Baetis sp. | 3 | 7 | | | 3 |
| Heptageniidae | | | | | |
| Heptagenia sp. | | 4 | | 11 | 57 |
| Stenonema sp. | 39 | 427 | | 327 | 325 |
| Stenacron sp. | 9 | 15 | | 14 | 6 |
| Oligoneuriidae | | | | | |
| Isonychia sp. | 2 | 4 | | 3 | 4 |
| Tricorythidae | | | | | |
| Tricorythodes sp. | 1 | | | 1 | |
| Plecoptera | | | | | |
| Pteronarcyidae | | | | | |
| Pteronarcys sp. | 8 | 2 | | 3 | 28 |
| Trichoptera | | | | | |
| Hydropsychidae (Immature) | 414 | 135 | | 44 | 208 |
| Hydropsyche bidens | 647 | 519 | | 355 | 407 |
| H. orris | 20 | 7 | | 6 | 24 |
| H. simulans | 72 | 20 | | 38 | 26 |
| Cheumatopsyche sp. | 12 | 6 | | 8 | 6 |
| Potamyia sp. | 354 | 123 | | 225 | 113 |
| Leptoceridae | | | | | |
| Nectopsyche sp. | | 1 | | | |
| Mollusca | | | | | |
| Gastropoda | | | | | |
| Physidae | | | | | |
| Physa sp. | | | 64 | | |
| Annelida | | | | | |
| Hirudinea | | | | | |
| Rhynchobdellida | | | | | |
| Glossiphoniidae | | | 1 | | |
| Platyhelminthes | | | | | |
| Turbellaria | | | | | |
| Tricladida | | | | | |
| Planariidae | | | 32 | | |
| Total No. of Organisms | 1932 | 1292 | 97 | 1228 | 1298 |
| Total No. of Taxa | 15 | 17 | 3 | 16 | 15 |

DC: Discharge Canal
Note: to convert no. of organisms counted to No./m^2 multiply by 6.25.
Prepared by UHL Limnology Section

Table 25

Daily Numbers of Fish Impinged at the Duane Arnold Energy Center
January - December 1990

| Day of the Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 10 | 11 | 7 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 2 | 10 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 3 | 0 | 3 | 23 | 15 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| 4 | 10 | 0 | 26 | 20 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 5 | 3 | 8 | 42 | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5 | 6 | 0 | 6 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| 7 | 12 | 0 | 15 | 15 | 1 | 7 | 0 | 1 | 1 | 0 | 1 | 0 |
| 8 | 3 | 15 | 5 | 20 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 9 | 0 | 12 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 2 | 6 | 33 | 0 | 5 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 11 | 5 | 0 | 118 | 0 | 3 | 1 | 0 | 0 | 4 | 0 | 0 | 1 |
| 12 | 5 | 0 | 204 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 2 |
| 13 | 0 | 20 | 232 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 |
| 14 | 4 | 0 | 145 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 6 |
| 15 | 0 | 0 | 53 | 3 | 0 | 1 | 5 | 0 | 0 | 1 | 0 | 3 |
| 16 | 0 | 0 | 24 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 3 | 0 |
| 17 | 0 | 0 | 32 | 0 | 0 | 13 | 0 | 0 | 0 | 1 | 1 | 0 |
| 18 | 0 | 0 | 17 | 7 | 0 | 10 | 0 | 0 | 3 | 1 | 3 | 1 |
| 19 | 0 | 12 | 6 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 5 |
| 20 | 25 | 15 | 14 | 0 | 1 | 4 | 0 | 0 | 0 | 1 | 0 | 0 |
| 21 | 8 | 20 | 5 | 4 | 0 | 10 | 0 | 3 | 0 | 0 | 12 | 0 |
| 22 | 0 | 5 | 18 | 0 | 0 | 8 | 0 | 0 | 0 | 1 | 0 | 0 |
| 23 | 10 | 15 | 30 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 0 |
| 24 | 0 | 15 | 30 | 2 | 0 | 3 | 0 | 0 | 0 | 3 | 4 | 0 |
| 25 | 1 | 9 | 23 | * | 3 | 0 | 0 | 3 | 4 | 0 | 6 | 0 |
| 26 | 0 | 11 | 24 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 10 | 0 |
| 27 | 0 | 15 | 35 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 4 | 1 |
| 28 | 20 | 30 | 20 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 |
| 29 | 10 | -- | 5 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 3 | 0 |
| 30 | 10 | -- | 8 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 31 | * | -- | 5 | - | 1 | - | 0 | 3 | - | 0 | - | 0 |
| Total | 133 | 227 | 1261 | 121 | 21 | 82 | 16 | 16 | 14 | 14 | 55 | 21 |
| Annual Total | | 1981 | | | | | | | | | | |

*No count taken

Table 26

Comparison of Average Values for Several Parameters at Upstream, Downstream, and Discharge Canal Locations at the Duane Arnold Energy Center During Periods of Station Operation* - 1990

| Parameter | Upstream (Sta. 2) | Discharge Canal (Sta. 5) | Mixing Zone (Sta. 3) | Downstream (Sta. 4) |
|---|---|---|---|---|
| Temperature ($^oC$) | 9.6 | 16.8 | 10.6 (110)** | 10.6(110)** |
| Dissolved Solids (mg/L) | 322 | 1191 | 384 (119) | 357 (110) |
| Total Hardness (mg/L) | 276 | 791 | 309 (112) | 298 (108) |
| Total Phosphate (mg/L) | 0.26 | 1.41 | 0.33 (127) | 0.29 (112) |
| Nitrate (mg/L as N) | 6.6 | 15.4 | 7.0 (106) | 6.8 (103) |
| Iron (mg/L) | 0.38 | 1.7 | 0.43 (113) | 0.28 (73) |

* Excludes the period July 11 through September 19, 1990
**Percent of upstream level (   )

Table 27

Comparison of Average Yearly Values for Several Parameters in the Cedar River Upstream from the Duane Arnold Energy Center*
1972-1990

| Year | Mean Flow** (cfs) | Turbidity (NTU) | Total $PO_4$ (mg/L) | Ammonia (mg/L-N) | Nitrate (mg/L-N) | BOD (mg/L) | Total Hardness (mg/L) |
|---|---|---|---|---|---|---|---|
| 1972 | 4,418 | 22 | 1.10 | 0.56 | 0.23 | 5.7 | 253 |
| 1973 | 7,900 | 28 | 0.84 | 0.36 | 1.5 | 4.0 | 250 |
| 1974 | 5,580 | 29 | 2.10 | 0.17 | 4.2 | 4.7 | 266 |
| 1975 | 4,206 | 58 | 1.08 | 0.33 | 2.8 | 6.5 | 251 |
| 1976 | 2,082 | 41 | 0.25 | 0.25 | 2.8 | 7.3 | 233 |
| 1977 | 1,393 | 15 | 0.33 | 0.52 | 2.9 | 6.5 | 243 |
| 1978 | 3,709 | 23 | 0.26 | 0.22 | 4.4 | 3.3 | 261 |
| 1979 | 7,041 | 26 | 0.29 | 0.12 | 6.6 | 2.5 | 272 |
| 1980 | 4,523 | 40 | 0.34 | 0.19 | 5.4 | 4.3 | 238 |
| 1981 | 3,610 | 33 | 0.77 | 0.24 | 6.0 | 6.5 | 279 |
| 1982 | 7,252 | 43 | 0.56 | 0.23 | 8.0 | 5.1 | 274 |
| 1983 | 8,912 | 22 | 0.25 | 0.10 | 8.6 | 3.3 | 259 |
| 1984 | 7,325 | 40 | 0.32 | 0.10 | 5.9 | 3.9 | 264 |
| 1985 | 3,250 | 30 | 0.31 | 0.11 | 4.8 | 6.7 | 245 |
| 1986 | 6,375 | 33 | 0.26 | 0.10 | 6.8 | 3.7 | 285 |
| 1987 | 2,625 | 32 | 0.24 | 0.06 | 5.6 | 5.8 | 269 |
| 1988 | 1,546 | 28 | 0.30 | <0.16 | 2.8 | 9.6 | 246 |
| 1989 | 947 | 24 | 0.37 | 0.30 | 1.5 | 10.3 | 224 |
| 1990 | 5,061 | 33 | 0.29 | 0.20 | 7.3 | 4.8 | 283 |

* Data from Lewis Access location (Station 1)
**Data from Cedar Rapids gauging station

Table 28

Summary of Relative Loading Values (Average Annual Concentration x Cumulative Runoff) for Several Parameters in the Cedar River Upstream of the Duane Energy Center* 1972-1990

| Year | Mean Flow (cfs) | Cumulative** Runoff (in.) | Turbidity | Relative Loading Values | | | |
|---|---|---|---|---|---|---|---|
| | | | | Total $PO_4$ | Ammonia | Nitrate | BOD |
| 1972 | 4,418 | 9.24 | 203 | 10.2 | 5.2 | 2 | 53 |
| 1973 | 7,900 | 16.48 | 461 | 13.8 | 5.9 | 25 | 66 |
| 1974 | 5,580 | 11.64 | 338 | 24.4 | 2.0 | 49 | 55 |
| 1975 | 4,206 | 8.77 | 509 | 9.5 | 2.9 | 25 | 57 |
| 1976 | 2,082 | 4.35 | 178 | 1.1 | 1.1 | 12 | 32 |
| 1977 | 1,393 | 2.91 | 44 | 1.0 | 1.5 | 8 | 19 |
| 1978 | 3,709 | 7.74 | 178 | 2.0 | 1.7 | 34 | 26 |
| 1979 | 7,041 | 14.79 | 385 | 4.3 | 1.8 | 98 | 37 |
| 1980 | 4,523 | 9.45 | 378 | 3.2 | 1.8 | 51 | 41 |
| 1981 | 3,610 | 7.53 | 248 | 5.8 | 1.8 | 45 | 49 |
| 1982 | 7,252 | 15.13 | 651 | 8.5 | 3.5 | 121 | 77 |
| 1983 | 8.912 | 18.00 | 396 | 4.5 | 1.8 | 155 | 59 |
| 1984 | 7,325 | 15.22 | 609 | 4.9 | 1.5 | 90 | 59 |
| 1985 | 3,250 | 6.80 | 204 | 2.1 | 0.8 | 33 | 46 |
| 1986 | 6,475 | 13.11 | 433 | 3.4 | 1.3 | 89 | 49 |
| 1987 | 2,625 | 4.85 | 155 | 1.2 | 0.3 | 27 | 28 |
| 1988 | 1,546 | 2.85 | 80 | 0.9 | <0.4 | 8 | 27 |
| 1989 | 947 | 1.84 | 44 | 0.7 | 0.6 | 3 | 19 |
| 1990 | 5,061 | 9.34 | 308 | 2.7 | 1.9 | 68 | 45 |

* Data from Lewis Access location (Station 1)
**Data from Cedar Rapids gauging station